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DEPARTMENT OF COMMERCE

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SOME EARTH RESISTIVITY MEASUREMENTS

BY

F. W. LEE, J. W. JOYCE AND PHIL. BOYER

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SOME EARTH RESISTIVITY MEASUREMENTS[1]

By Frederick W. Lee,[2] J. W. Joyce,[3] and Phil Boyer[4]

INTRODUCTION

The value of ground resistivity measurements made on the surface of the earth as an index of structure below it is gradually becoming of increasing importance. While originally of direct interest to the mining engineer in the location of ore deposits it has found further applications in the location of various electrical resistivities. The functioning of power service and telephonic communications are more or less affected by the position of the various earth's resistivities relative to each other. The location of proper bridge, dam, and building foundations with the aid of resistivity measurements is today an accepted procedure.

The first record of resistivity measurements upon large bodies of the earth's crust was made by Rooney of the Carnegie Institution. Later Leonardon and Kelly described the results of resistivity measurements in connection with their practical applications. This method must not be taken as the one described in Patent 1163468, issued December 7, 1915 to C. Schlumkerger.

Although the procedure of measurement is relatively simple, interpretation of the results involves a large amount of study. Because of the great variety of discontinuities which embrace the ground structures, involving both a change of dimension as well as electrical properties, no simple mathematical system of analysis can be applied directly to these measurements. A new mathematical tool must be invented to meet these needs, hence the results must rest for the present upon extensive experimental work rather than possible theoretical deductions. Some of the difficulties encountered are set forth in this information circular.

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1 - The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6171."

2 - Supervising engineer, geophysical section, U. S. Bureau of Mines.

3 - Field Assistant, U. S. Bureau of Mines.

4 - Field assistant, U. S. Bureau of Mines.

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AVERAGE RESISTIVITY

For purposes of measurement two systems of determining the average resistivity of the earth are used. Their difference rests upon the type of boundary surface between which the material is located whose average resistivity is to be measured. The surfaces may be defined as nonenveloping, as shown in Figure 1, or as enveloping, as shown in Figure 2. In both cases ideal geometric configurations are assumed, and the average resistivity is computed upon this basis.

This geophysical method differs from the older one which mapped the electrical potential fields on the surface of the ground and from the form of these fields interpreted the materials associated with them but did not consider the numerical evaluation of these fields in terms of the associated material. The index number associated with the current and potential field in this paper is the resistivity. Furthermore, the resistivity can be measured separately from specimens taken from the ground and thereby allow direct correlation to those measurements made from the surface of the earth.

FACTORS INFLUENCING AVERAGE RESISTIVITY

Since a composite mass is measured in the ground the factors that influence this average must be considered. From this point another consideration deserves attention, namely, how does the average resistivity, when measured separately, differ from the combined average resistivity?

If the average resistivity of Figure 3 between T_1 and r_3 is ρ_1 and between r_3 and r_2 is ρ_2 what average resistivity is measured between r_1 and r_2 and what relation does this combined average resistivity bear to ρ_1 and ρ_2 respectively in this simple ideal case? This average resistivity change was due to the change of materials associated with the new portions of the potential field or depends upon the partition interval of r_3. The nearness of r_3 to r_1 and r_2 affects the average resistivity.

At first sight it would appear that the usual method of averaging would yield the resultant average but closer examination shows that a difference exists.

The common method of averaging is based on the following relation: (Average property of material) x (total amount of material) = sum of (individual properties of material) x (amount of each material). If resistivity is considered:

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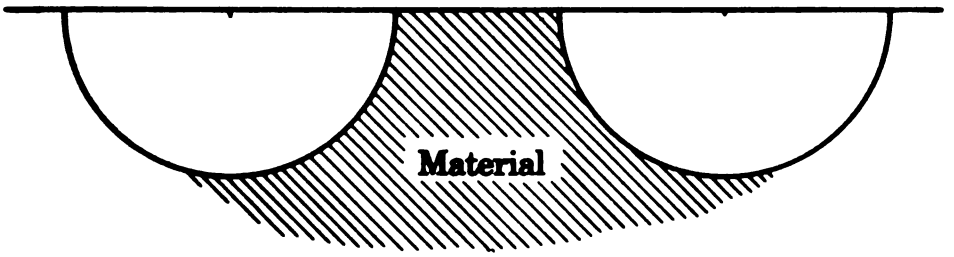

Figure 1.– Determination of earth resistivity when surface is nonenveloping

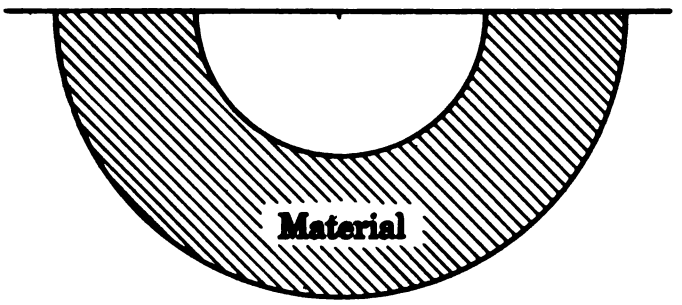

Figure 2.– Determination of earth resistivity when surface is enveloping

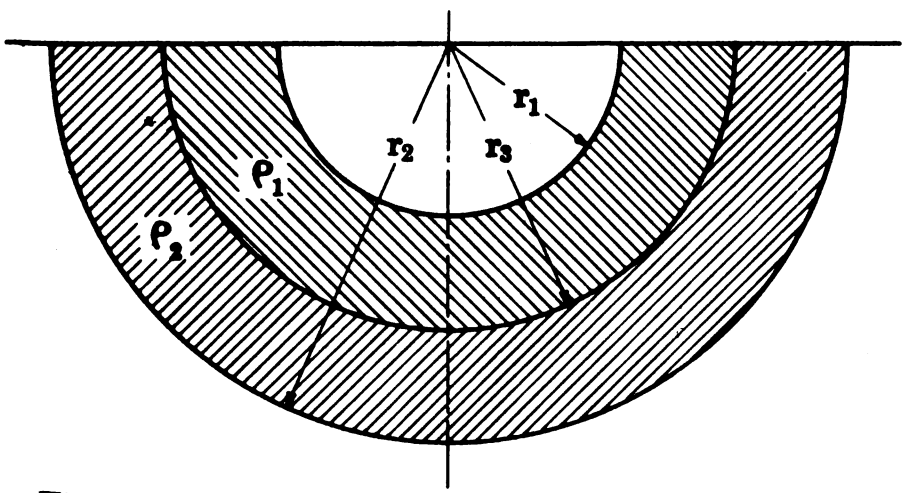

Figure 3.– Diagram to illustrate factors influencing average resistivity

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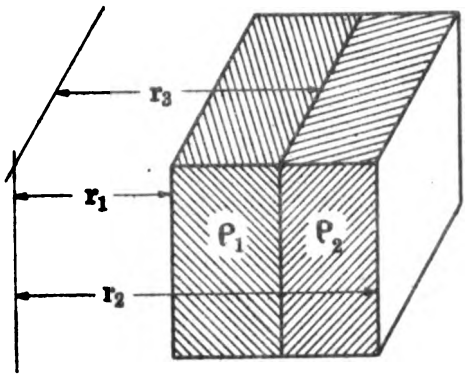

Figure 4.– Ideal electrical fields with no curvature; class A

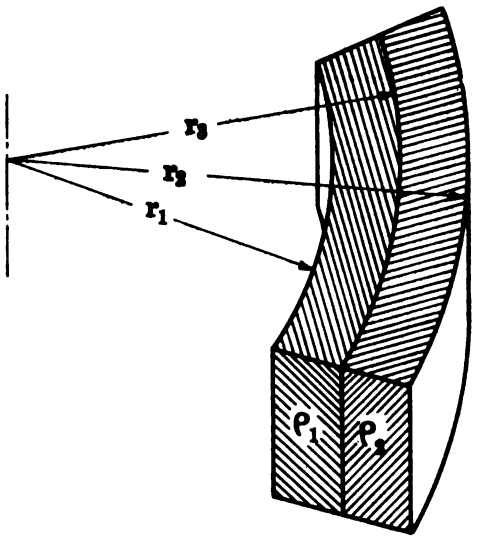

Figure 5.– Ideal electrical fields with curvature; class B

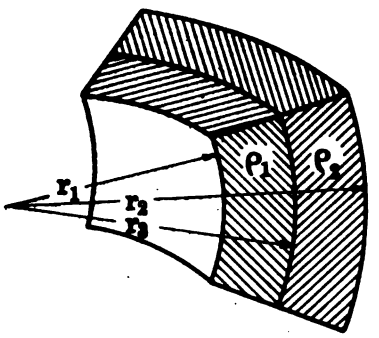

Figure 6.– Ideal electrical fields with double curvature; class C

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$$\rho_{ave}\ v_T = \rho_1 v_1 + \rho_2 v_2 + \text{-----} \rho_n v_n.$$

herefore

$$\rho_{ave} = \frac{\sum_1^n \rho_n v_n}{v_T} . \qquad (1)$$

por the premises in the above case:

$$\rho_{ave} = \left(\frac{r_3^3 - r_1^3}{r_2^3 - r_1^3}\right) \rho_1 + \left(\frac{r_2^3 - \rho_3^3}{r_2^3 - r_1^3}\right) \rho_2. \qquad (2)$$

n the other hand, if the average resistivity is computed from experimental obser-ations, then if R_{13} is the resistance between shell r_1 and v_3, R_{32} is the re-istance between shell r_3 and r_2, and R_{12} is the resistance between shell r_1 and 2. Then $R_{12} = R_{13} + R_{32}$, since the two shells are connected in series.

Computing the equivalent resistivity upon this electrical configuration, hich is the basis upon which ρ_1 and ρ_2 were measured separately, then

$$\frac{\rho_1}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_3}\right) + \frac{\rho_3}{2\pi}\left(\frac{1}{r_3} - \frac{1}{r_2}\right) = \frac{\rho_{eq}}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

R

$$\rho_{eq} = \left(\frac{r_3 - r_1}{r_1\ r_3}\right)\left(\frac{r_1\ r_2}{r_2 - r_1}\right)\rho_1 + \left(\frac{r_2 - r_3}{r_2\ r_3}\right)\left(\frac{r_1\ r_2}{r_2 - r_1}\right)\rho_2. \qquad (3)$$

t is noticed that the equivalent as expressed by equation (3) differs from the verage in equiation 2 of the previous case. The apparent percentages of ρ_1 and ρ_2 iffer in the two view-points and are a function of the geometrical configuration f the ideal fields. The first average equation (2), may be termed the volumetric verage, and the second average equation (3) may be termed the electrical average.

The ideal fields for this discussion may be divided into three classes: lass A, ideal electrical fields with no curvature, (fig. 4); class B, ideal elec-rical fields with 1 degree of curvature, (fig. 5); and class C, ideal electrical ields with 2 degrees of curvature, (fig. 6).

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For purpose of simplicity $r_2 = 2r_1$, and concentric cylindrical as well as concentric spherical curvatures were used in most of the field measurements.

How the respective effects of ρ_1 and ρ_2 influence the combined effect in the two methods of adveraging are shown in the following equations:

Class A - No curvature

$$\rho_{ave} = \frac{r_3 - r_1}{r_2 - r_1}\rho_1 + \frac{r_2 - r_3}{r_2 - r_1}\rho_2 .$$

$$\rho_{eq} = \frac{r_3 - r_1}{r_2 - r_1}\rho_1 + \frac{r_2 - r_3}{r_2 - r_1}\rho_2 .$$

Class B - One degree of concentric curvature

$$\rho_{ave} = \frac{r_3^2 - r_1^2}{r_2^2 - r_1^2}\rho_1 + \frac{r_3^2 - r_3^2}{r_2^2 - r_1^2}\rho_2 .$$

$$\rho_{eq} = \left(\log \frac{r_3}{r_1} \Big/ \log \frac{r_2}{r_1}\right)\rho_1 + \left(\log \frac{r_2}{r_3} \Big/ \log \frac{r_2}{r_1}\right)\rho_2 .$$

Class C - Two degrees of concentric curvature

$$\rho_{ave} = \left(\frac{r_3^3 - r_1^3}{r_2^3 - r_1^3}\right)\rho_1 + \left(\frac{r_2^3 - r_3^3}{r_2^3 - r_1^3}\right)\rho_2 .$$

$$\rho_{eq} = \left(\frac{r_3 - r_1}{r_1 \quad r_3}\right)\left(\frac{r_1 \quad r_2}{r_2 - r_1}\right)\rho_1 + \left(\frac{r_2 \quad r_3}{r_2 \quad r_3}\right)\left(\frac{r_1 \quad r_2}{r_2 - r_1}\right)\rho_2 .$$

It is seen that only when there is no curvature the average and the equivalent resistivity are identical. In the other cases the discrepency becomes greater with the degrees of curvature.

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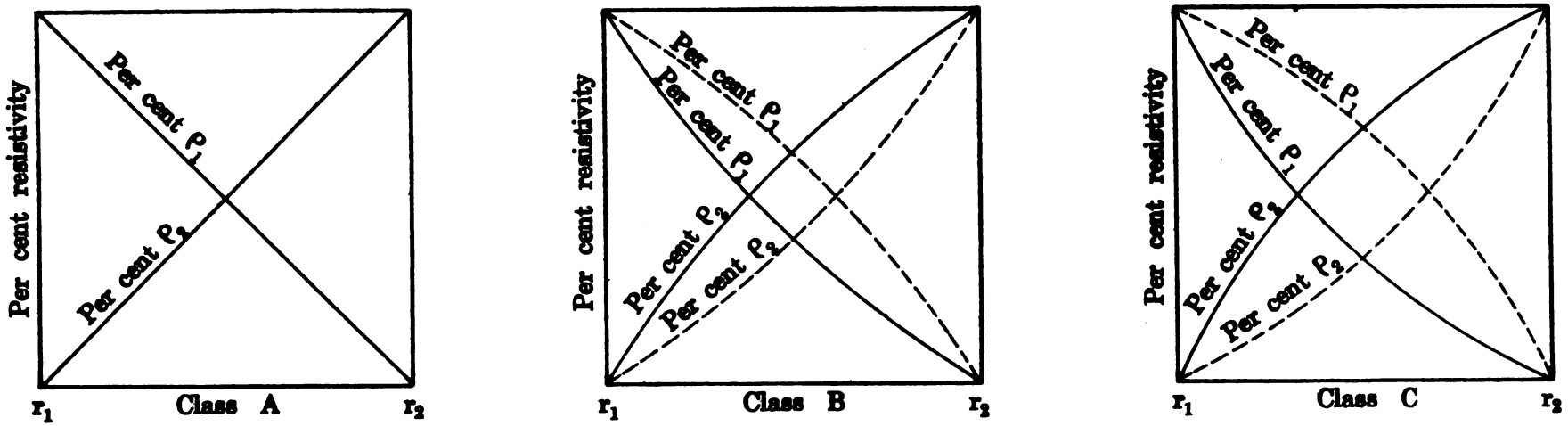

Figure 7.– Effects of ρ_1 and ρ_2 for average and equivalent resistivity of three classes of curvature in electrical fields

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The results of these equations are shown graphically in Figure 7.

The dotted curves are for average resistivity and the full line curve for equivalent resistivity in classes B and C, Figure 7. It is seen that the general effect of the curved field is to emphasize the resistivity at the point of greatest curvature, being greater for 2 degrees of curvature than for 1 degree.

The first of the above cases does not allow a practical field application; the second is practical but not very rapid in field manipulation. The third is the most direct and has been used in this paper.

All methods of measuring resistivity involve curved fields; hence, a direct comparison of resistivity as measured from the surface to that when extracted from below and measured separately will show differences in equivalent resistivity in composite structures.

A new inhomogeneity of structure passes into the picture much more rapidly at the points of greatest curvature; hence from this the nonenveloping surfaces used by Gish and Rooney will give more sensitive indications than the enveloping surfaces used by Leonardon in some instances. With slight changes in the procedure for making field observations the Gish-Rooney methods can be used to great advantage.

The potential observations must be taken in such a manner as to allow a greater effect by the new ground introduced into observation than by the released ground due to change of potential points. Yet the changes must not be too great and must allow enough old ground in the picture as a basis of comparison to the new ground introduced.

RESISTIVITY ABOUT A SINGLE ELECTRODE

The single electrode method consists of using two current terminal connections, usually iron stakes, for connecting current to the ground. The distance between the two stakes is made great enough for ideal hemispherical potential shells in a uniform medium. Measurements are taken far enough away from the stake not to be influenced by the form of the stake itself. The field around the stake itself is usually ellipsoidal, becoming hemispherical a very short distance from the stake itself in homogeneous ground. A large number of potential fields immediately around a ground state are discussed quite thoroughly by Ollendorff.[5]

The distance separating the two stakes depends upon the depth of survey required and must be beyond the immediate stake field to be almost hemispherical in form.

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5 - F. Ollendorff, Erdstrome: Julius Springer, Berlin, 1928. pages 20-23.

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The error introduced by assuming a hemispherical field of constant concentricity around the current stake can be computed from the ideal field condition. For this purpose consider the two current connections as C_1 and C_2 in Figure 8.

The plane of symmetry will be at b, and the distance from b to each stake is a. The potentials at P_1 and P_2 are to be equal, and the per cent x, of a determined for this condition. The point P_2 is chosen to the other side of C_2 to compute the greatest dissymmetry from the ideal eccentric condition. To work with homogeneous symmetrical equations define the distance P_1 from b as ka, where k is a percentage of a, in this instance always less than unity. In equalizing the potential at P_1 and P_2 a homogeneous material introduces the following equation:

$$\frac{1}{(1 - K)a} - \frac{1}{(1 + K)a} = \frac{1}{a\,x} - \frac{1}{2a + ax} .$$

$$\text{whence} \quad x = -1 + \sqrt{1 - k + \frac{1}{k}}$$

The error committed by not placing C at infinity may be computed from this relation. The results are presented in Table 1, expressed in percentage of a.

Table 1.- Maximum variation of symmetry around a stake electrode.

$\frac{K}{\%\ a}$	$\frac{1}{K}$	$1 + \frac{1}{K} - K\sqrt{1 + \frac{1}{K} - K}$		$\frac{X}{\%\ a}$	$\frac{C_2P_1}{\%\ a}$	$C_2P_2 - C_2P_1$	$\frac{C_2P_2 - C_2P_1}{C_2P_1}$
0.95	1.053	1.103	1.050	0.05	0.05	0.00	0
.90	1.111	1.211	1.100	.10	.10	.00	0
.85	1.177	1.327	1.152	.152	.15	.002	1.3
.80	1.250	1.450	1.205	.205	.20	.005	2.5
.75	1.333	1.583	1.258	.258	.25	.008	3.2
.70	1.429	1.729	1.314	.314	.30	.014	4.6
.65	1.538	1.888	1.375	.375	.35	.025	7.2
.60	1.667	2.067	1.437	.434	.40	.034	8.5
.55	1.818	2.268	1.506	.506	.45	.056	12.4
.50	2.000	2.500	1.582	.582	.50	.082	16.4
.45	2.222	2.772	1.665	.665	.55	.115	20.8
.40	2.500	3.100	1.761	.761	.60	.161	26.8
.35	2.857	3.507	1.874	.874	.65	.224	34.5
.30	3.333	4.033	2.010	1.010	.70	.310	44.3
.25	4.000	4.750	2.180	1.18	.75	.43	57.4
.20	5.000	5.800	2.410	1.410	.80	.610	76.2
.15	6.667	7.517	2.740	1.741	.85	.89	104.7
.10	10.000	11.900	3.450	2.05	.90	1.55	172.0
.05	20.000	20.950	4.580	3.580	.95	3.63	382.0
.0	∞	∞	∞	∞	1.00	∞	∞

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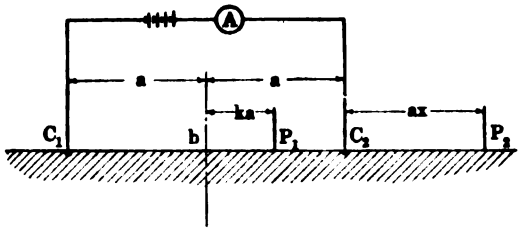

Figure 8. – Diagram to illustrate error introduced by assuming a hemispherical field of constant concentricity

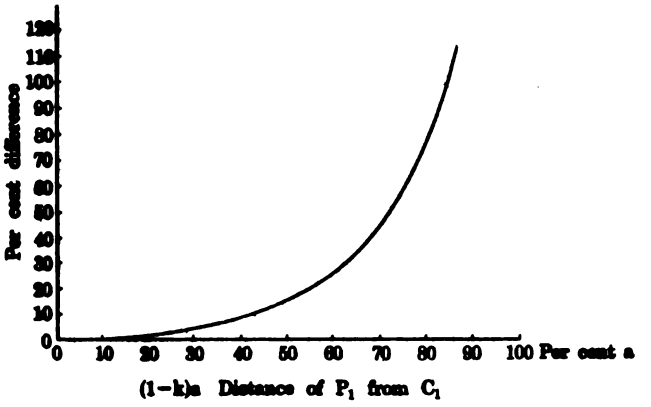

Figure 9. – Error curve plotted from results of Table 1

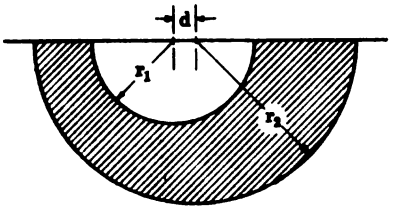

Figure 10. – Diagram showing two nonconcentric hemispheres

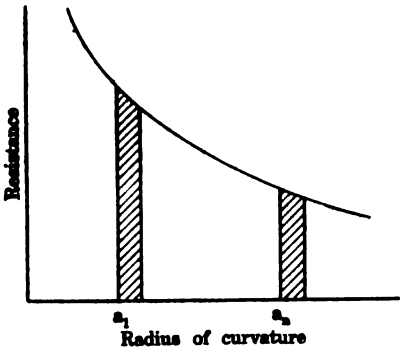

Figure 11. – Curve plotted to illustrate resistance between each section of concentric hemispheres

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or k = 100 per cent the value for x becomes infinity, as was expected. A separation of 5,000 feet between the stakes would allow exploration to a depth of 1,000 feet without a great degree of error.

As the shells become unsymmetrical with respect to the stake C_2 they may still be approximated by hemispherical ideal shells which are nonconcentric. Because of this nonconcentricity the usual relation of resistivity to the geometrical dimensions becomes slightly more involved. Consider the two nonconcentric hemispheres shown in Figure 10.

Applying several conformal space transformations it can be shown that the relation of the resistance and the resistivity is given by the relation for the first approximation as

$$R = \frac{\rho}{2\pi}\left\{\frac{r_1\left[r_2^2-(d-a)^2\right]-r_2\left[r_1^2-a^2\right]}{\left[r_1^2-a^2\right]\left[r_2^2-(d-a)^2\right]}\right\}$$

Where

$$a = \frac{d^2+r_1^2-r_2^2+\sqrt{(r_2^2-r_1^2-d^2)^2-4d^2r_1^2}}{2d}$$

By using this relation it is seen that the resistance between concentric and nonconcentric hemispheres does not differ greatly, even with considerable eccentricity.

Example: If $r_2 = 3$ and $r_1 = 1.5$ and $d = .5$ and ρ is set at 1 then R = 0.0517 ohm for the nonconcentric condition and R = 0.0529 ohm for the concentric case, a difference of about 2 per cent.

For convenience in calculating resistivity gradient curves Table 2 is inserted for computing the equivalent resistivity at various radii for concentric hemispherical shells.

When averaging the resistivity between curved surfaces and in particular a spherical one, the total resistance may be considered to consist of concentric hemispheres.

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The total resistance is the algebraic sum of all individual hemispheres.

Let r_1 , r_2 , r_3 , etc., be the resistance between each shell whose thickness is unity and a_1 , a_2 , a_3 , etc., be the respective radii of these ideal shells sufficiently large to avoid effect of curvature.

Then the total resistance $R = r_1 + r_2 + r_3 + \text{etc.}$ and $R = \frac{\rho}{2\pi}$

$$\left[\frac{1}{a_1^2} + \frac{1}{a_2^2} + \frac{1}{a_3^2} + = \frac{1}{a_n^2}\right]$$

If a curve is plotted between the resistance of each section of these bowl as represented in Figure 11, it is noticed that section a_1 contributes much more to the total resistance than a_n, whereas the volume of a_n is much greater than that of a_1.

Table 2. - Computation of resistance at various radii between concentric hemispheres.

10-foot intervals

$p = k \times \text{Resistance}$

Distance from stake (r)	$\frac{1}{r}$	$\frac{1}{r_1} - \frac{1}{r_2}$	$k = \frac{2\pi \times 30.5}{\frac{1}{r_1} - \frac{1}{r_2}}$
10	0.1000		
		0.0500	3.833
20	.0500		
		.0167	11.475
30	.0333		
		.0083	23.090
40	.0250		
		.0050	38.330
50	.0200		
		.0033	58.070
60	.0167		
		.0024	79.850
70	.0143		
		.0018	106.460
80	.0125		
		.0014	136.880
90	.0111		
		.0011	174.220
100	.0100		

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25-foot intervals

Distance from stake (r)	$\frac{1}{r}$	$\frac{1}{r_1} - \frac{1}{r_2}$	K
25	0.04000		
		0.02000	9,582
50	.02000		
		.00667	28,730
75	.01333		
		.00330	58,070
100	.01000		
		.00200	95,820
125	.00800		
		.001333	143,730
150	.00667		
		.000943	203,220
175	.005714		
		.000714	268,400
200	.005000		
		.000556	344,670
225	.004444		
		.000444	431,190
250	.004000		
		.000364	526,400
275	.003636		
		.000303	632,500
300	.003333		
		.000256	748,600
325	.003077		
		.000220	871,100
350	.002857		
		.00191	1,003,300
375	.002666		
		.000166	1,154,500
400	.002500		
		.000147	1,303,600
425	.002353		
		.000131	1,462,900
450	.002222		
		.000117	1,638,000
475	.002105		
		.000105	1,825,000
500	.0019047		
		.0000953	2,011,000
525	.0019047		

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525	.0019047		
		.0000666	2,213,000
550	.0018181		
		.0000790	2,426,000
575	.0017391		
		.0000724	2,647,000
600	.0016667		
		.0000667	2,875,000
625	.001600		
		.0000616	3,111,000
650	.0015384		
		.0000569	3,363,000
675	.0014815		
		.0000529	3,633,000
700	.0014285		
		.0000493	3,887,000
725	.0013793		
		.0000460	4,166,000
750	.0013333		
		.0000430	4,457,000
775	.0012903		
		.0000403	4,755,000
800	.0012500		
		.0000379	5,053,000
825	.0012121		
		.0000356	5,383,000
840	.0011765		
		.0000336	5,704,000
875	.0011429		
		.0000318	6,023,000
900	.0011111		
		.0000300	6,388,000
925	.0010811		
		.0000285	6,724,000
950	.0010526		
		.0000270	7,093,000
975	.0010256		
		.0000256	7,486,000
1000	.0010000		

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50-foot intervals

Distance from stroke (r)	$\frac{1}{r}$	$\frac{1}{r_1} - \frac{1}{r_2}$	K
50	0.020000		
		0.010000	14,160
100	.010000		
		.003333	57,490
150	.006667		
		.001667	114,980
200	.005000		
		.001000	191,600
250	.004000		
		.000667	287,500
300	.003333		
		.000476	402,600
350	.002857		
		.000357	536,800
400	.002500		
		.000278	689,400
450	.002222		
		.000222	862,400
500	.002000		
		.0001819	1,053,500
550	.0018181		
		.0001514	1,266,000
600	.0016667		
		.0001283	1,494,000
650	.0015384		
		.0001098	1,745,000
700	.0014286		
		.0000953	2,011,000
750	.0013333		
		.0000833	2,301,000
800	.0012500		
		.0000735	2,607,000
850	.0011765		
		.0000654	2,930,000
900	.0011111		
		.0000585	3,276,000
950	.0010526		
		.0000526	3,643,000
1000	.0010000		

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100-foot intervals

Distance from stake (r)	$\frac{1}{r}$	$\frac{1}{r_1} - \frac{1}{r_2}$	$K = \frac{2\pi \times 30.5}{\frac{1}{r_1} - \frac{1}{r_2}}$
100	0.010000		
		0.005000	38,330
200	.005000		
		.001667	114,750
300	.003333		
		.000833	230,900
400	.002500		
		.000500	383,300
500	.002000		
		.000333	580,700
600	.001667		
		.000238	805,200
700	.001429		
		.000179	1,070,600
800	.001250		
		.000139	1,378,700
900	.001111		
		.000111	1,724,700
1000	.001000		

hence the tendency to overemphasize the resistance near the center. Obviously the average shell is somewhere between the two extremes. A simple calculation will show that it is the geometrical mean between a_1 and a_n. The foregoing indicates that owing to the field curvature effects a difficulty arises in determining the resistivity of new material. There is a certain limit of accuracy in measuring the resultant resistivity in terms of the separate constituent resistivities. At present the change of resistivity is of importance, and it is hoped that proper analysis of the degree or amount of change will also be used as a factor in resistivity analysis. There is considerable experimental evidence to indicate that the depth effect is $\sqrt{2\ r_1\ r_2}$ or the geometric mean multiplied by the square root of two.

Even for simple forms of stratification the evaluation of the resistivity of newly introduced stratas from resultant average resistivities involves a large amount of mathematical analysis. If possible the Bureau of Mines will issue circulars later describing how it is done with the necessary formulas and charts.

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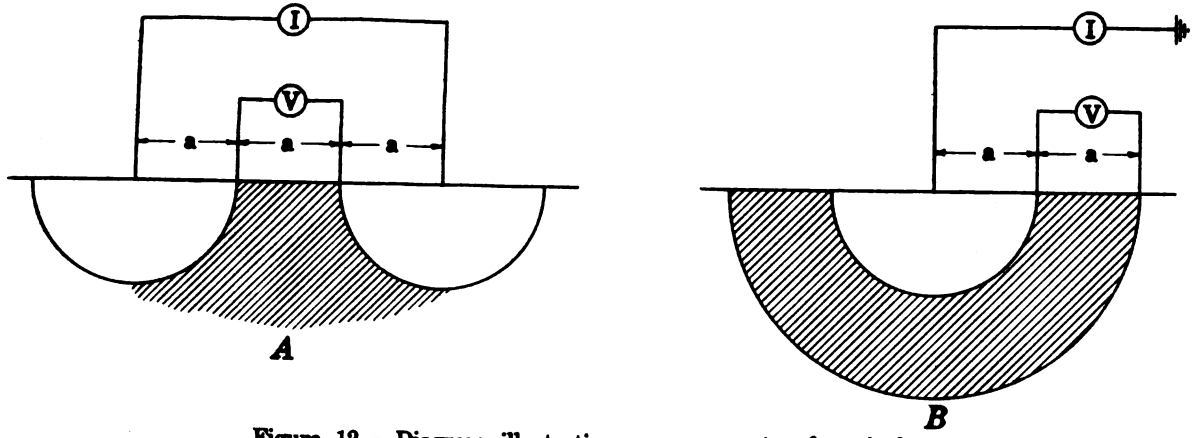

Figure 12. – Diagram illustrating measurements of equivalent earth resistivity: *A*, By Gish-Rooney method, using constant stake intervals; *B*, by measurements around one stake

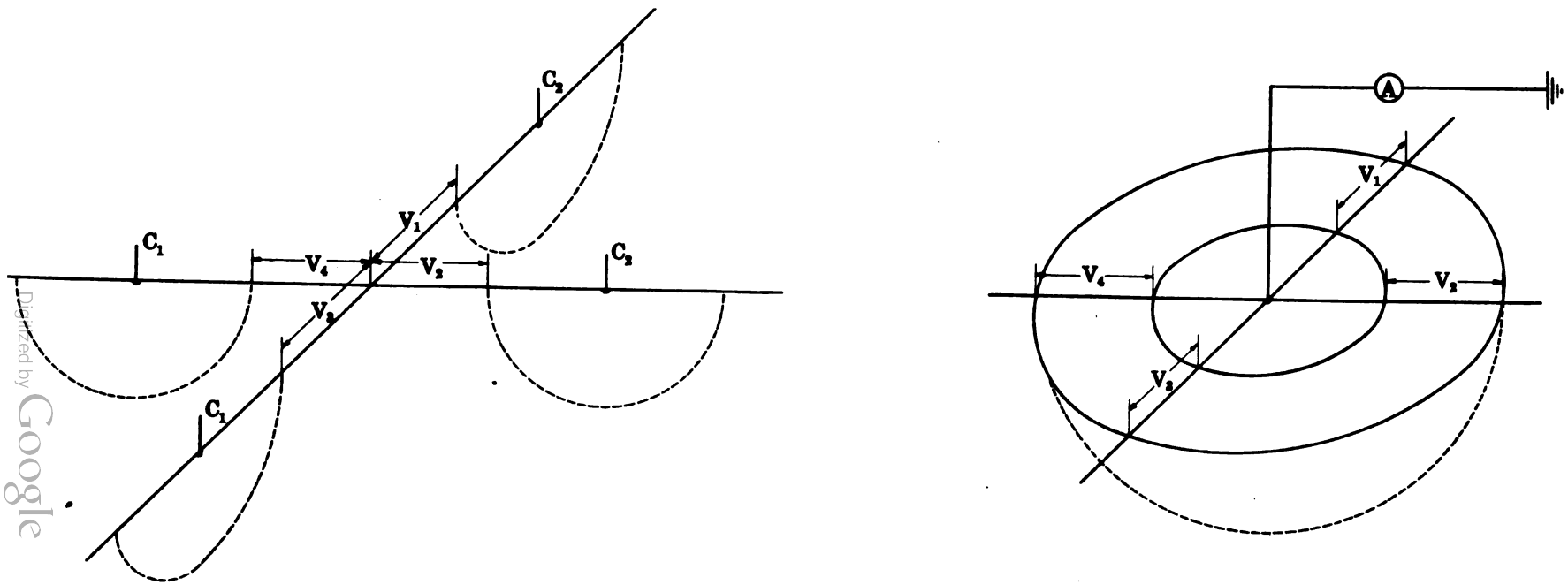

Figure 13. – Modification of method of measuring earth resistivity to extend interpretation of earth structure

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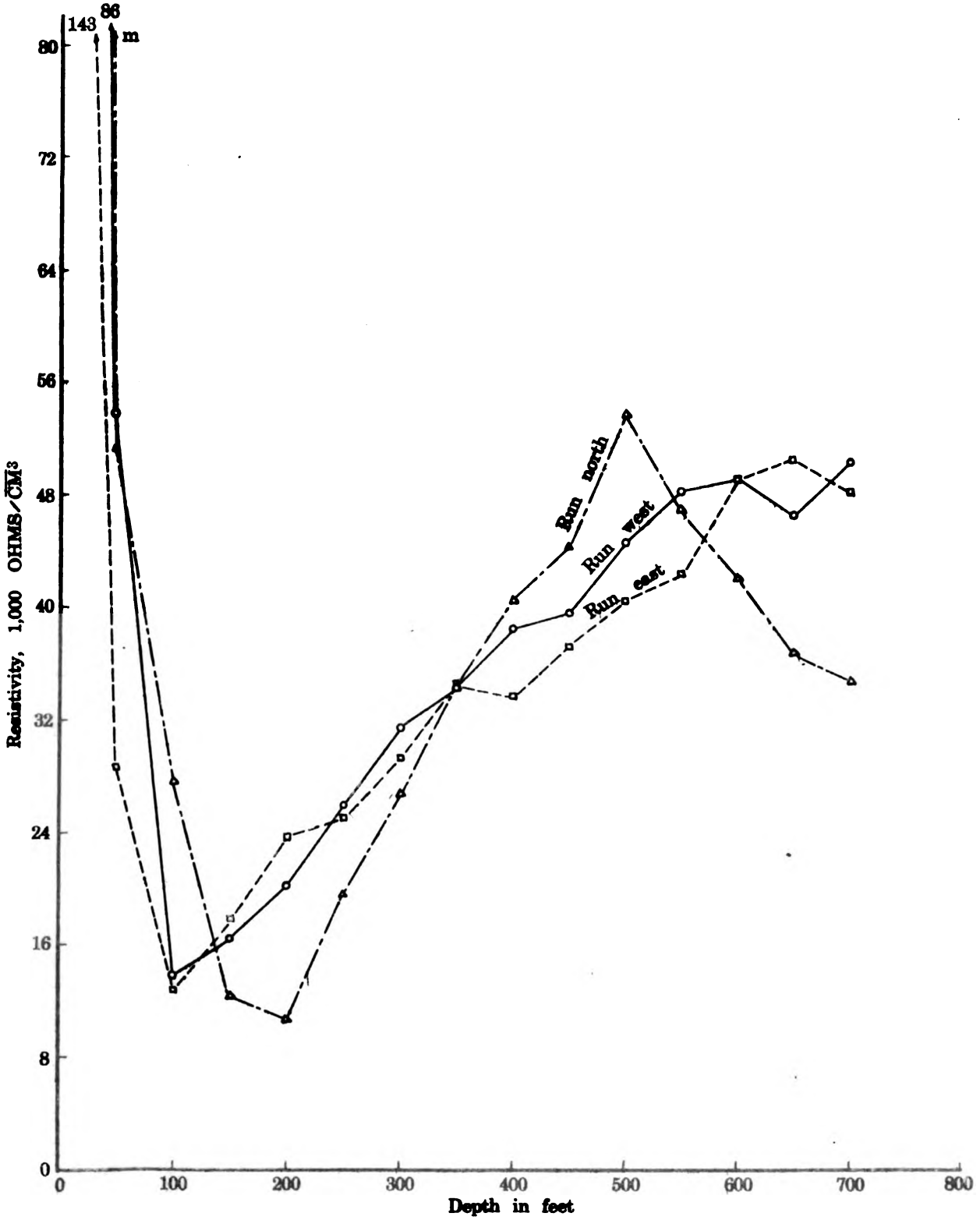

Figure 14. – Resistivity curve of ground, showing horizontal stratification

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METHODS FOR MEASURING EARTH RESISTIVITY

There are two general methods for measuring equivalent earth resistivity own in Figure 12 in A and B.

The Gish-Rooney method is illustrated at A with stant stake intervals as indicated. The resistivity may also be measured around a single stake shown in B of igure 12. The other stake for all intents and purposes may be considered at infinity. The equivalent electrical resistivity in both cases is computed by the formula

$$\rho_{eq} = 2\pi R a,$$

where $R = \frac{v}{I}$ ohms and a = distance in centimeters, as indicated in Figure 2.

This system admits to extend further the interpretation of the geological tructure as shown in Figure 12.

In place of measuring the total average potential, as in Figure 12 A, it is dvisable to split the potential interval into halves and measure the average resistivity in the four directions as shown in Figure 13.

The directional change of average resistivity allows further interpretations egarding structure. It is seen in the two systems that the maximum curvature surfaces are reversed. The system on the left introduces effects of average resistivity variation more quickly than that on the right. On the other hand, the central take method allows much faster operation in the field.

A typical resistivity curve in which horizontal stratification exists is hown in Figure 14. Dissymetry toward the north is found to occur after 500 feet.

SURFACE AND STRUCTURE EFFECTS ON RESISTIVITY

For geological interpretation two distinct effects must be considered in esistivity surveys, one a purely local or surface effect, the other a deep-seated ne. Irregularities due to conducting material near the surface if equipotential ines are drawn give similar pictures, yet the underlying ground may be entirely ifferent in the two separate cases. This method of considering only the form of he field is liable to be misinterpreted for this reason.

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This is illustrated in Figure 15 and Figure 16 with the equipotential lines a, b, c, d, and e, in the two cases. They both indicate the surface irregularity at A. However, the absolute potentials are 1.3, 1.5, 1.8, 2. and 2.4 in the first case and 2.3, 2.5, 2.8, 3.0, and 3.4 in the second case. The difference in each is the same, yet the equivalent electrical resistivity is greatly different in the two cases. It also shows that if resistivity measurements are made upon the surface the results will be different if the interval of evaluation is chosen too closely together.

This is best shown in Figure 17 by curve A. The interval of computation of resistivity is shown by the horizontal line through each point. The surface irregularities appear at a, b, c, and d. When the intervals are taken at greater intervals and averaged according to the diagrams of Figure 12, B, the curve, Figure 17, B, is obtained. This curve bears only a slight relation to A yet is computed directly from the same data.

A typical curve of resistivity is shown in Figure 18. The bottom of the hole drilled was 170 feet. The effect of good-conducting slate is clearly shown, as well as the beginning of the trap work. This hole was extrapolated electrically to a depth of 600 feet and shows a low-resistivity layer at 350 to 400 feet, followed by high-resistivity material.

Figure 19 is another illustration with a drill record. The definition between the surface and conglomerate is as well as the trap on the west line, very clearly indicated by the resistivity curves. There is some mineralization before the trap rock is reached. There seems to be some indication that the trap is encountered earlier on the east line or that the trap dips toward the west. Much more evidence is necessary on drilled territory to determine finally whether simple methods of this type will suffice. The change in resistivity gradient apparently bears a direct relation to the geological stratifications.

COMPARISONS OF MEASUREMENTS

In ground which is stratified into layers parallel to the surface the resistivity measured by the equal interval method or central stake method will differ but slightly in the form of the curve. But more often the results as measured all differ from each, leading to contradictions in interpretations. An example of this is shown in Figure 20. The drill record shows 20 feet of surface material, 50 feet of conglomerate and sandstone, 64 feet of slate, 9 feet of limestone, 30 feet of slate and 2 feet of limestone, followed by trap. The hole terminated in 19 feet of trap rock. The curves show the result of using the Gish-Rooney equal-interval method and the central-stake electrode with the resultant equivalent electrical resistivity plotted separately. The resistivity measured toward the north was averaged with the resistivity measured toward the south.

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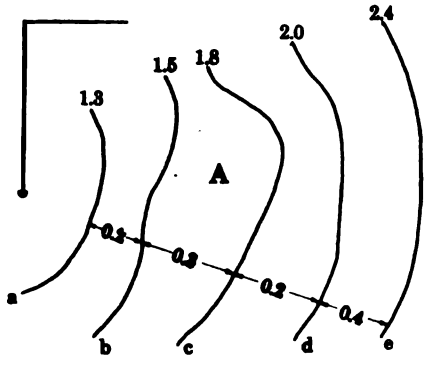


Figure 15.— Diagram showing local or surface effect at A at equipotential lines a, b, c, d, and e

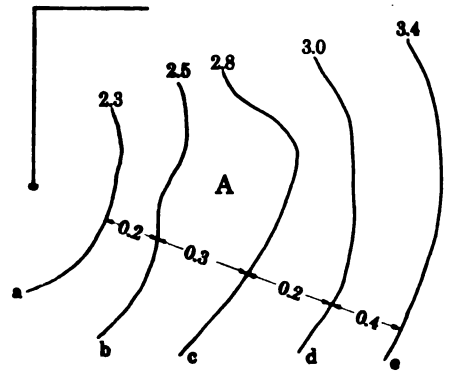
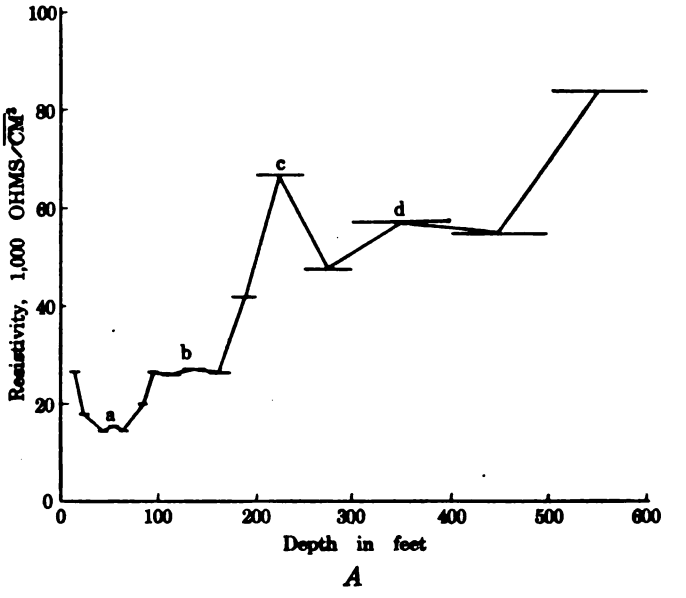


Figure 16.— Diagram showing deep-seated effect at A at equipotential lines a, b, c, d, and e



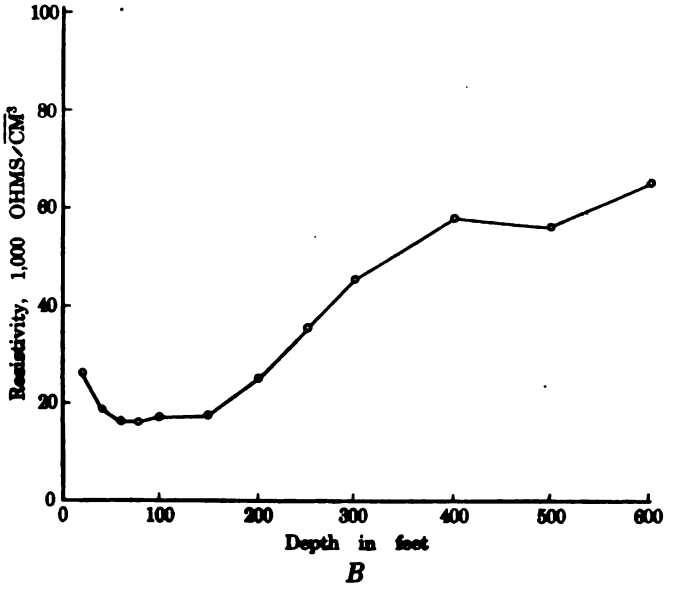


Figure 17.— Diagram showing different results obtained by varying intervals of computation of resistivity

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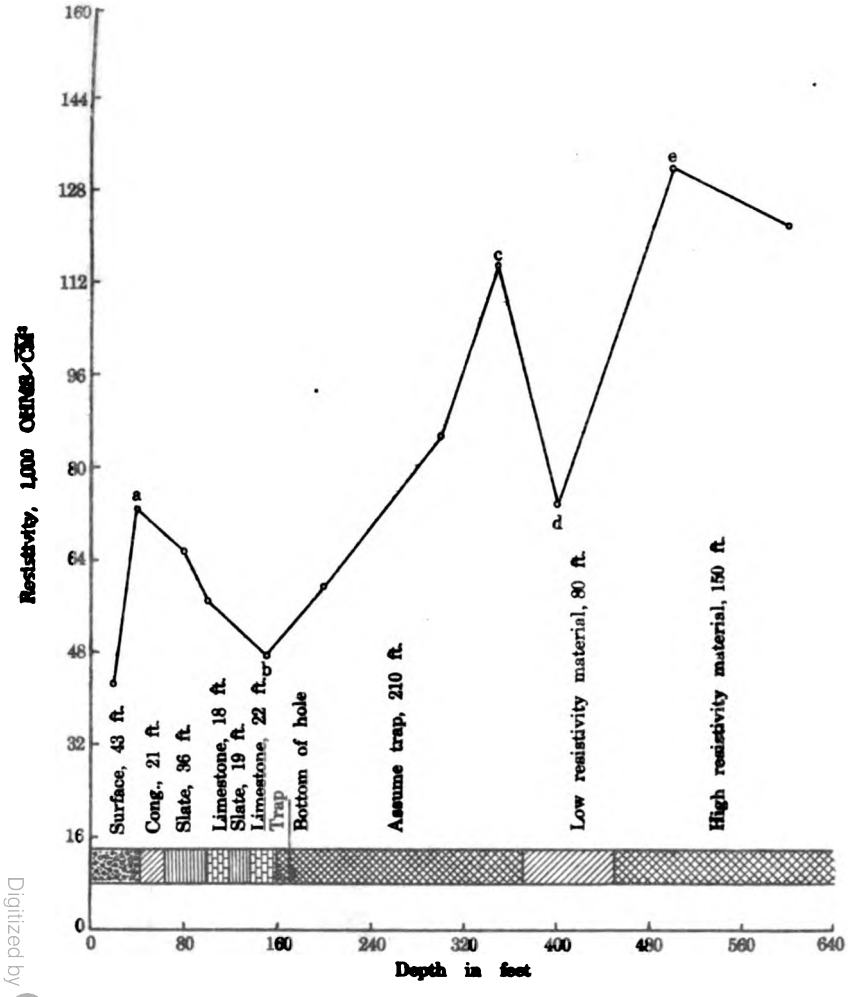

Figure 18. – Typical resistivity curve, with drill record

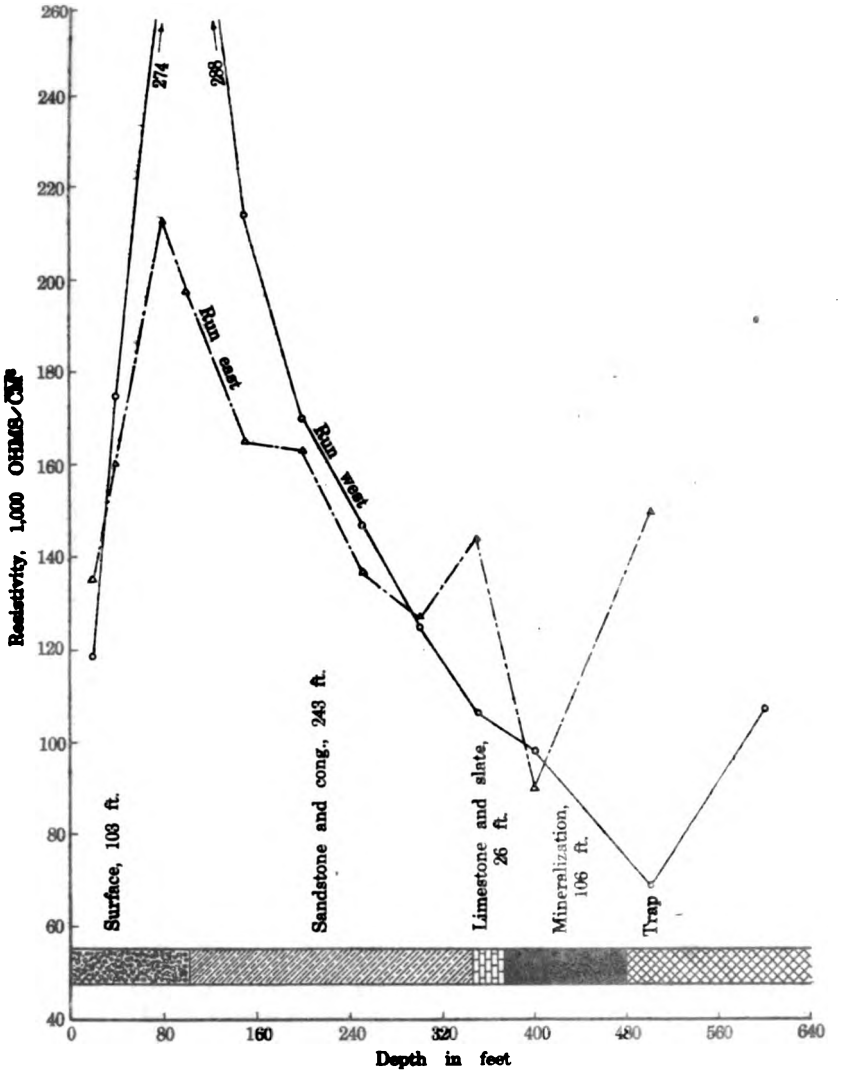

Figure 19. – Typical resistivity curve, with drill record

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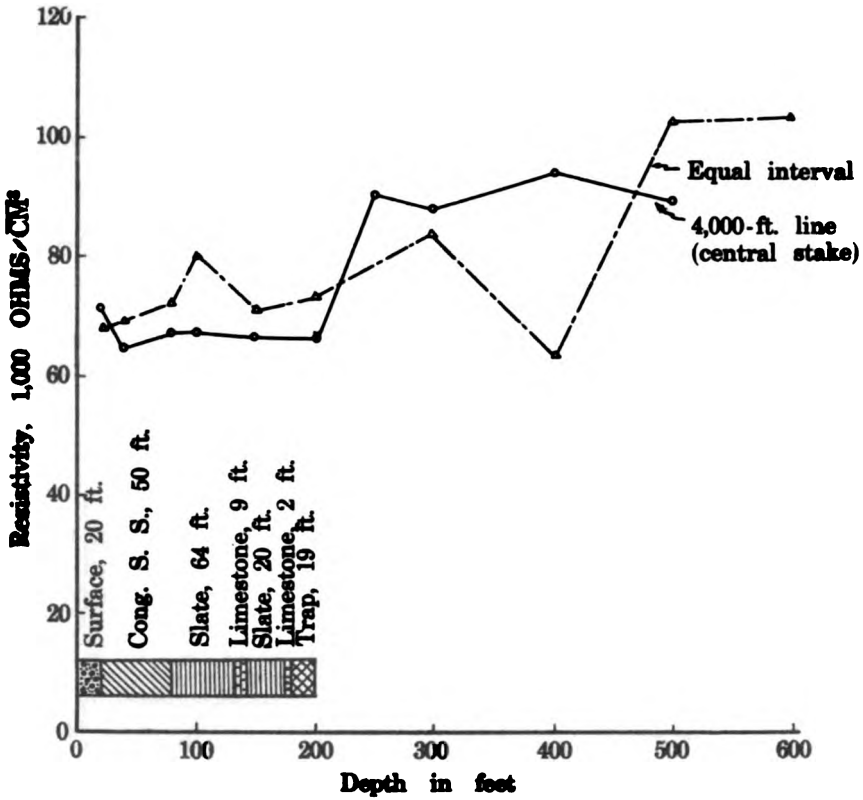

Figure 20.— Equal-interval and central-stake runs north and south averaged

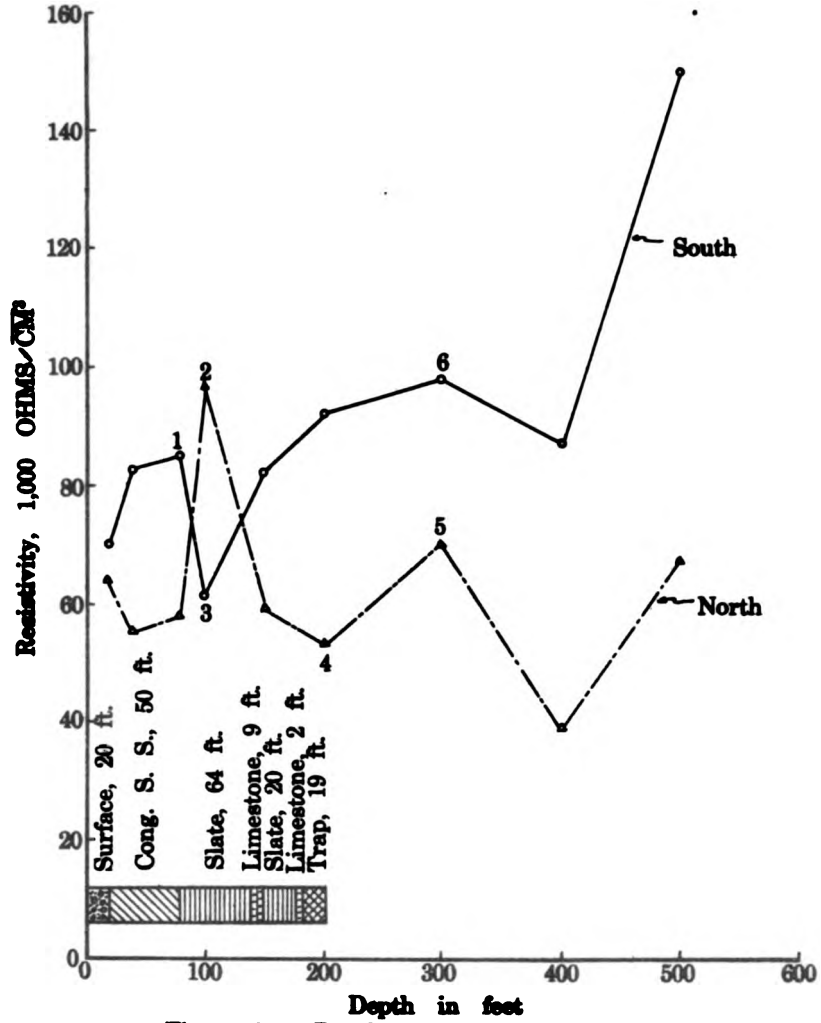

Figure 21.— Results with equal-interval method

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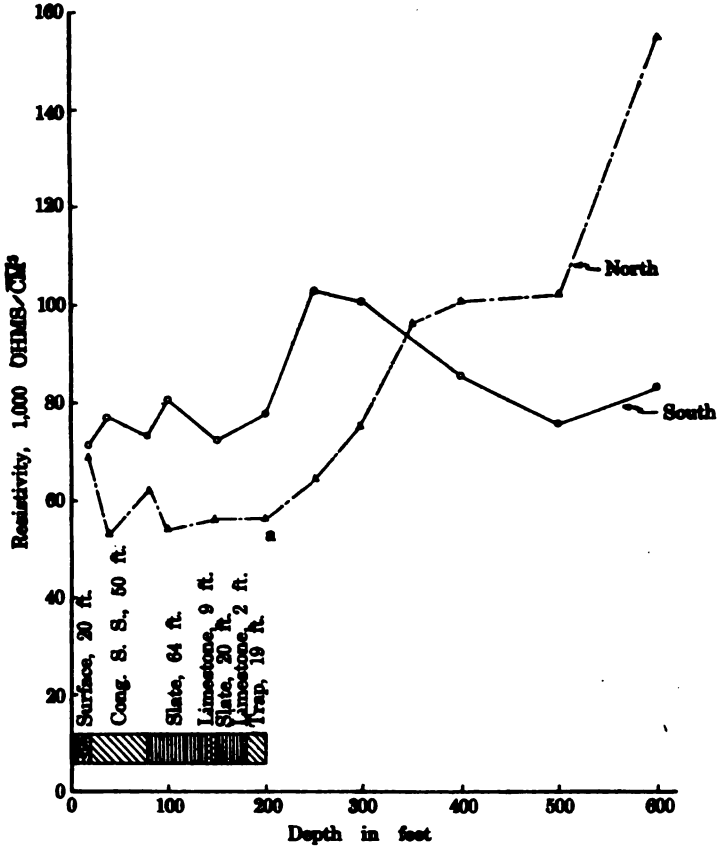

Figure 22.– Results with central-stake method

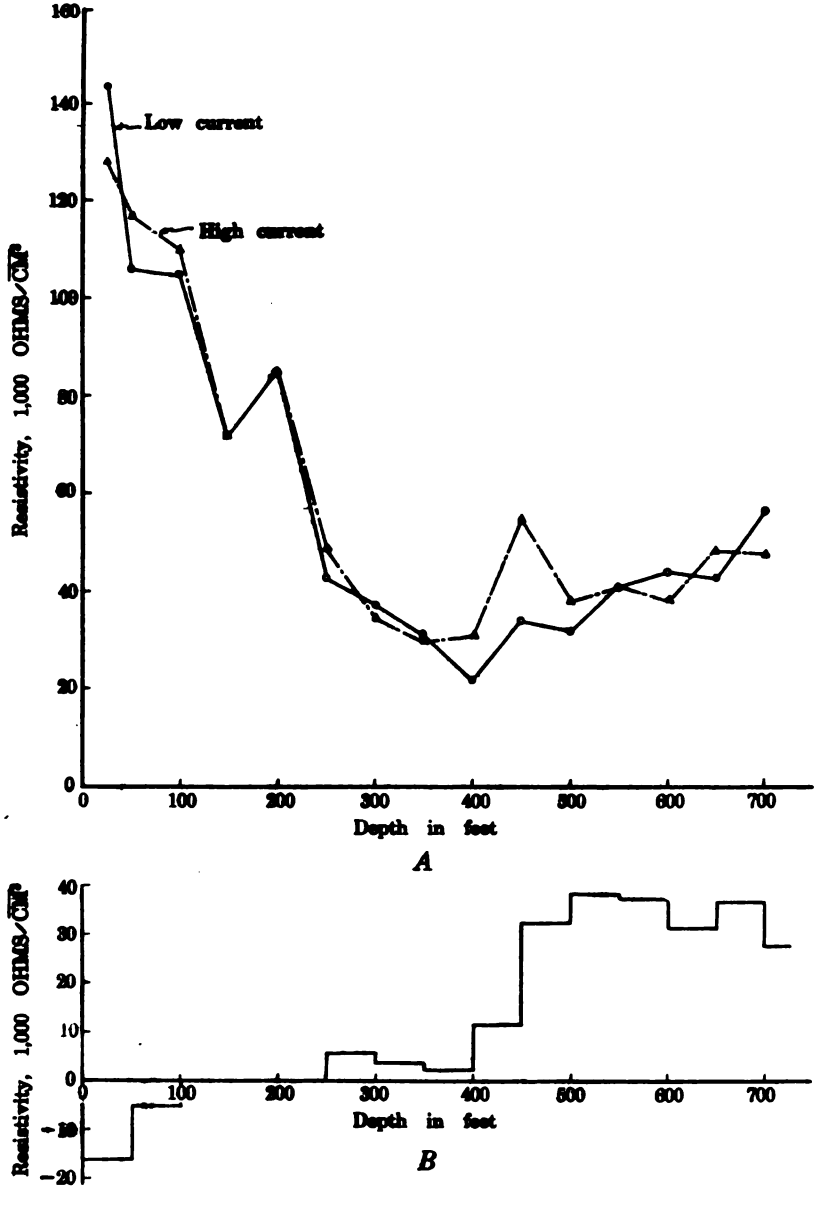

Figure 23.– Variation in resistivity with applied voltage

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Results would indicate that slate had a higher resistivity than conglomerate on the equal-interval method, and no change was indicated at all in the central-electrode method, which is contrary to what should be expected from the drill record. The equal-interval method also indicates decreased resistivity after 300 feet, but no such indiciation is shown with the central-electrode method. The general values of resistivity encountered by each method are of the same order of magnitude. This would lead to a conclusion stating a complete failure in principle of this method in this instance. The facts are that slate has a lower resistivity than either conglomerate or trap.

After dividing the equal interval method, as indicated in Figure 20, and measuring rhe resistivity in each direction separately the results of Figure 21 were obtained. Indications are that the slate is encountered earlier at point 1 measured toward the south then measured towards the north. It also pinches out toward the south and broadens toward the north since the effect of the trap rock is clearly indicated at 4 and also at 3. After points 5 and 6 there is a decrease in resistivity again in both directions. It is therefore seen that if these two curves are averaged entirely different interpretations would be made, having only slight value compared to the drill record.

When the separate directions are considered in the measurement about the single electrode the same general effect is noted as in the two electrode methods. This is shown in Figure 22. The trap rock is clearly indicated at a in this diagram.

Owing to the dip of the beds, the resultant average vitiates the recognition of points of discontinuity in Figure 20, and could more easily be deduced by measuring to the middle point.

From the results of a geophysical survey at this point the indications would show that no hole should have been drilled here for low conductivity mineralization.

DIFFERENTIATIVE RESISTIVITY MEASUREMENTS

That various rocks have a relative different volt-ampere or resistivity characteristic has been shown by Pullen[6]. Experimental evidence tends to confirm these measurements made in the laboratory. Each rock formation has its own resistivity characteristics in this respect. If a region of low conductivity exists it may be possible upon this basis to gain some insight into the nature of the conductivity by changing the potential gradient.

6 - Pullen, M. T., Tentative Method of Making Resistivity Measurements of Drill Cores and Hand Specimens of Rocks and Ores: Inf. Circ. 6141, Bureau of Mines, May, 1929, 9 pp.

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That there is a variation of resistivity depending upon the applied voltage can be seen from Figure 23.

This diagram shows the change of resistivity which resulted from changing the current by about 50 per cent. It is seen that the resistivity decreased in some case and increased in others with no general rule governing the relation.

Curve A shows the resistivity as a function of the depth, and curve B shows the change of resistivity considering the effect of the overlying layers. There is still a need of a simple basis for computing the value of the resistivity in a layer from the variation of the average resistivity measured at the surface. That computations and charts will form the key to structural analysis of this type is a forgone conclusion.

STRATIGRAPHY

By choosing the points of observation at close enough intervals it is possible to follow the contour of the various geological beds. Owing to the rapid dip and the very diverse types of stratification and also the variation of the resistivity in direction of the stratification considerable skill is necessary for the proper interpretation of the results. As an illustration of the idea the following two resistivity measurements made at points 100' apart can be used to illustrate this principle.

Examining the resistivity curve of Figure 24 the discontinuities are strikingly marked at the points from 1 to 10. On examining the measurements at 100 feet further south (fig. 25) corresponding points are number alike. The dip indicated is very great in this interval, at first about 50 feet in 100 feet and later 100 feet in 100 feet.

Much additional work is necessary to interpret problems completely in this manner. In this way it is possible to locate also strata having a low or high electrical resistance and to obtain some idea of the relative conduction of current in the ground from one point to another. It indicates where to take precautionary measures against electrolysis and where protection is not so important because high-conductivity beds tend to carry more current than low-conductivity beds, although so far there are no direct ground surveys and measurements that might be cited to substantiate this theory completely.

To avoid telephonic interference it has been customary in some countries to provide a return of the rail current to a transformer at certain intervals to avoid stray currents of excessive magnitude. The proper location of these transformers with an idea of maximum economy is also largely a factor of the ground resistivity and stratigraphy.

The surge impedance of the ground itself is also to some extent a factor in electrical operation of power systems as well as wireless, which depends upon the electrical properties of the ground.

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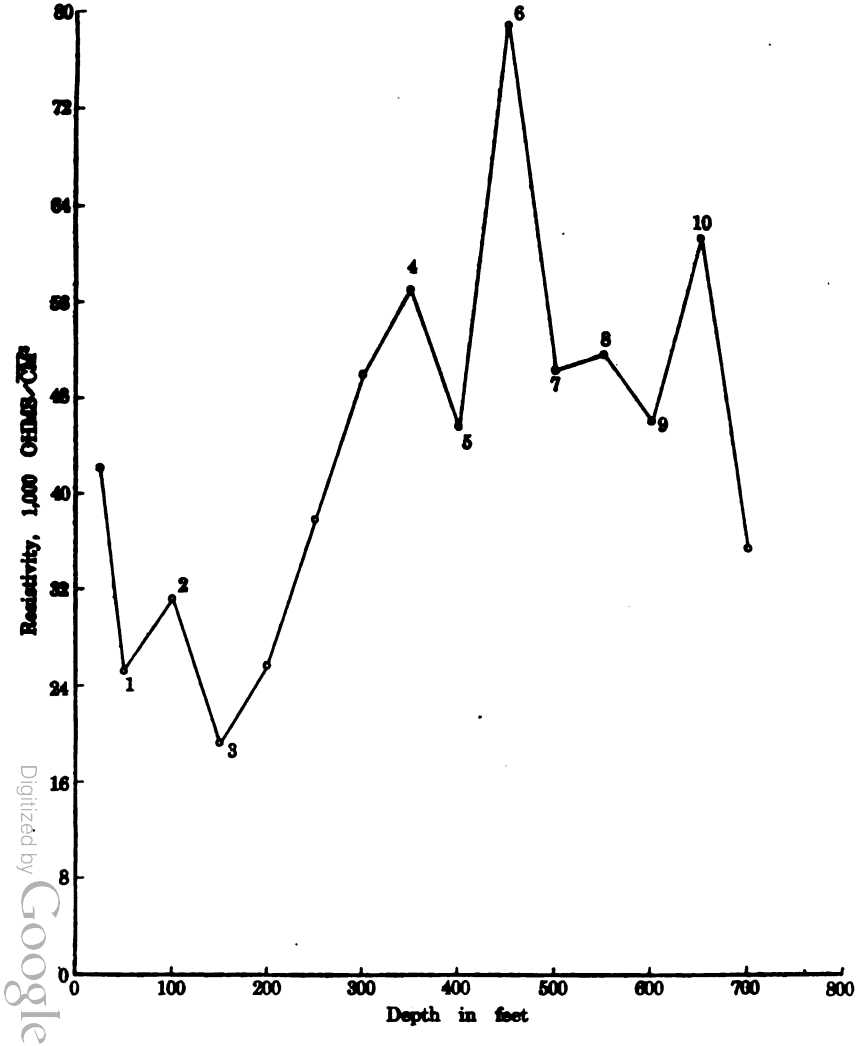

Figure 24.— Resistivity curve, showing discontinuities

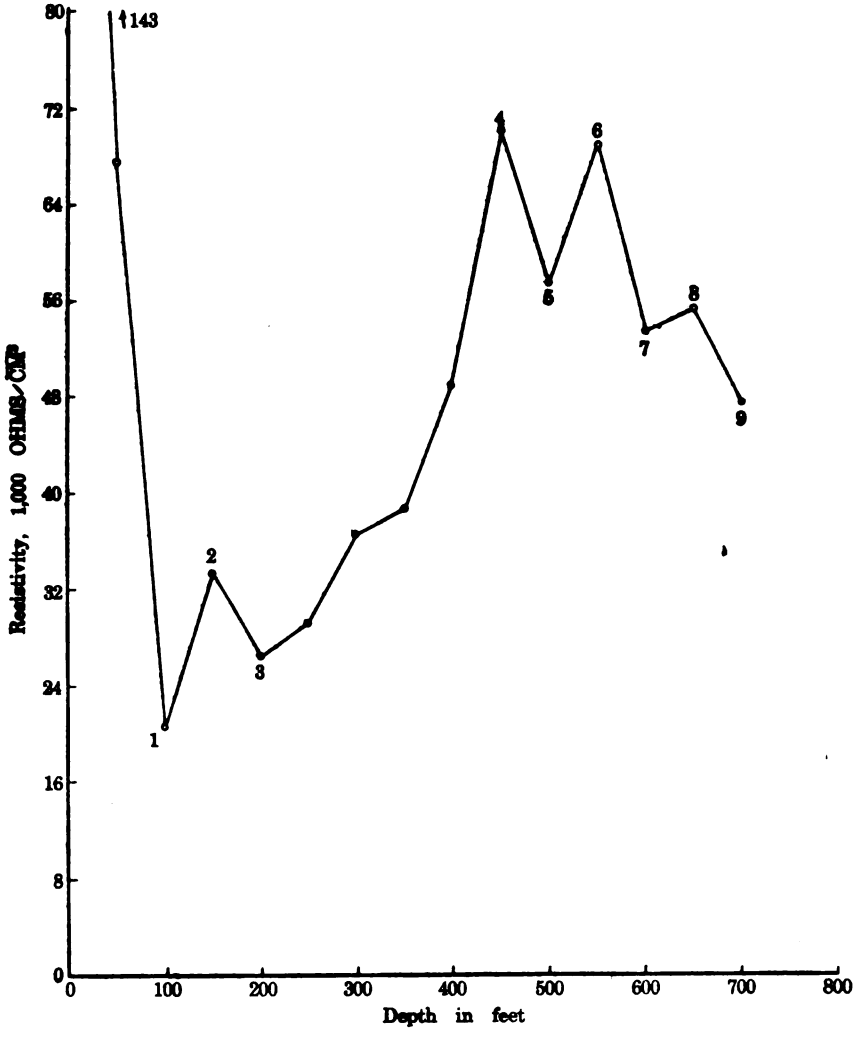

Figure 25.— Resistivity curve at point 100 feet south of that of Figure 24

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